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An Advanced Method for Studying Electrotransport in Thin Films Using Electrical Resistance

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Resistance measurements are of great interest in electrotransport investigations, because they provide a tool to measure structural changes due to momentum exchange of electrons with ions. An advantage of this method is that changes in resistance are observable well before voids can be visually seen. High precision electrical resistance measurements of vapor deposited stripes were made using a special sample design which permitted investigations of five different portions of the samples. In Fig. 1, four different sample designs are shown. One can distinguish the electrodes "A" and the gage section. The resistance in area I, can be determined by measuring the voltage drop between the terminals 1 and 2, and so on. When the samples were subjected to current densities of about 5×10^5 A/cm^2 in an air environment, a temperature profile formed along the specimen having its maximum temperature in the middle of the sample. In this case voids occurred in the area, which, looking in the direction of electron flow, first has a smaller cross sectional area, and which is marked "B". With the design shown in Fig. 1a it is not possible to monitor possible resistance changes to the left of area I and to the right of area V. Therefore, the design was modified to that shown in Fig. 1b. The specimens of type a and b possess two wider parts "A" at the end of the stripe. This design could cause curved potential lines in the specimen just at the critical point "B". In order to overcome this, composite samples were made using silver for the electrodes and aluminum for the gage section (Fig. 1c). Silver proved to be better than Cr or Ni because of its low resistivity. For specimen fabrication, silver of about 7000 Å in

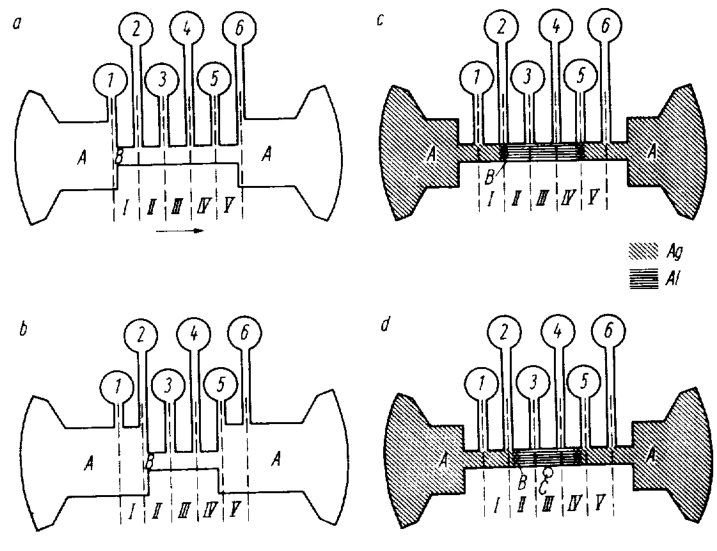

Fig. 1. Shapes of specimens used for resistance measurements

thickness was vapor deposited, overlapping the silver by about 1 mm at each end. Due to the thicker silver film and the higher melting point of silver compared to aluminum, the electrotransport in the silver layer was so small that it could be comparatively neglected. In a further modification the overlap areas were shifted towards the center, so that the aluminum portion and zone "B" was totally confined between potential leads number 2 and 5. The results presented in this paper were obtained with specimens of this latter design, i.e., of Fig. 1d. The experiments were performed in a styrofoam container in order to avoid temperature fluctuations. During the experiments reference temperatures were taken at a point marked "C" near the middle of the sample. All experiments performed with specimens of the various types just described show by proper interpretation basically the same results. In Fig. 2 the relative resistance change of the five areas and the reference temperature are plotted vs. time. The end-point of these curves mark the failure of the sample due to opening of the circuit. The following features can be seen: 1) The resistance of the area which, looking in the direction of electron flow, first has a smaller cross-sectional area, i.e., area II, increases substantially with time. 2) Two pronounced steps of resistance increase can be seen similar to those

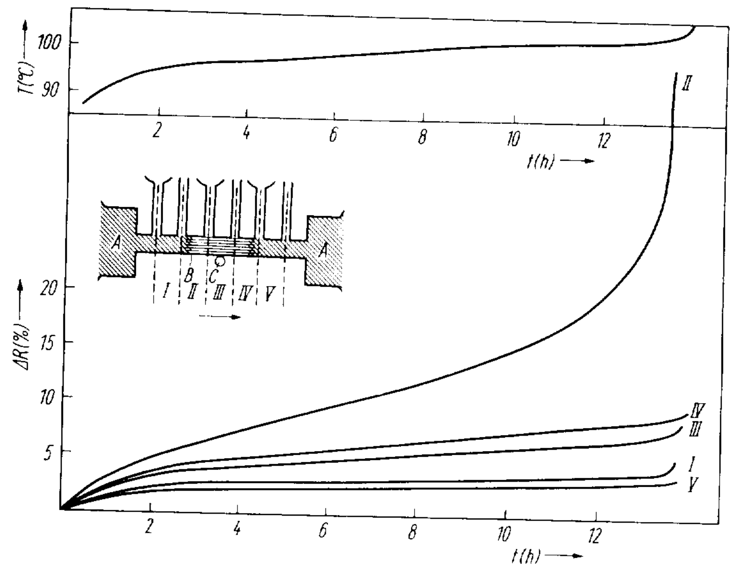

Fig. 2. Relative resistance and temperature of an aluminum sample (of the type of Fig. 1d) vs. time. Environment: air; current density: 4.3×10^5 A/cm^2; sample thickness: 2145 Å; substrate: glass

observed under different experimental conditions by Rosenberg and Berenbaum (1). (These authors performed their investigations in a silicon-oil bath of constant temperature.) One observes a fairly shallow increase up to 12 h and a steep one from 12 h until failure. Samples which were subjected to higher current densities than 5×10^5 A/cm^2 usually showed only the rapid increase. 3) The resistance change in area I, III, IV, and V, if any, is extremely small if one takes the temperature increase into consideration. Two further points should be noted: 1) When the sample was maintained at constant temperature, (oil bath) the resistance in areas III and IV did not remain constant as above during the experiment. An increase in area IV and a slight decrease in area III could be observed. 2) Samples of the same type as above which were subjected to alternating current showed no change in resistance. The resistance increase is interpreted to be due to void formation. Because of the accumulation of material at the anode, one would expect a decrease in resistance in area IV. This was never observed. It is, therefore, concluded that ions which were removed from their initial positions by momentum exchange are likely to be deposited in a way which gives no contribution to the conductivity. In Fig. 3 scanning electron microscopy pictures are shown. One can see that the ions which were transported through the specimen by momentum exchange are deposited in form of hillocks and probably whiskers. The hillocks have the largest density in area IV and the smallest in area III where the temperature is highest. Likewise, voids can be observed across the whole specimen, with the highest density naturally at the cathode end. Also interesting is the left end of area II where the opening of the circuit occurred. Here the aluminum has probably melted shortly before failure. The larger hillocks have an average height of 20 times the film thickness, and are well separated from each other. They give, therefore, no appreciable contribution to the conductivity. This probably explains why a decrease in resistance in area IV was not observed.

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References

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See Short Note by R. E. Hummel and W. A. Slippy Jr.

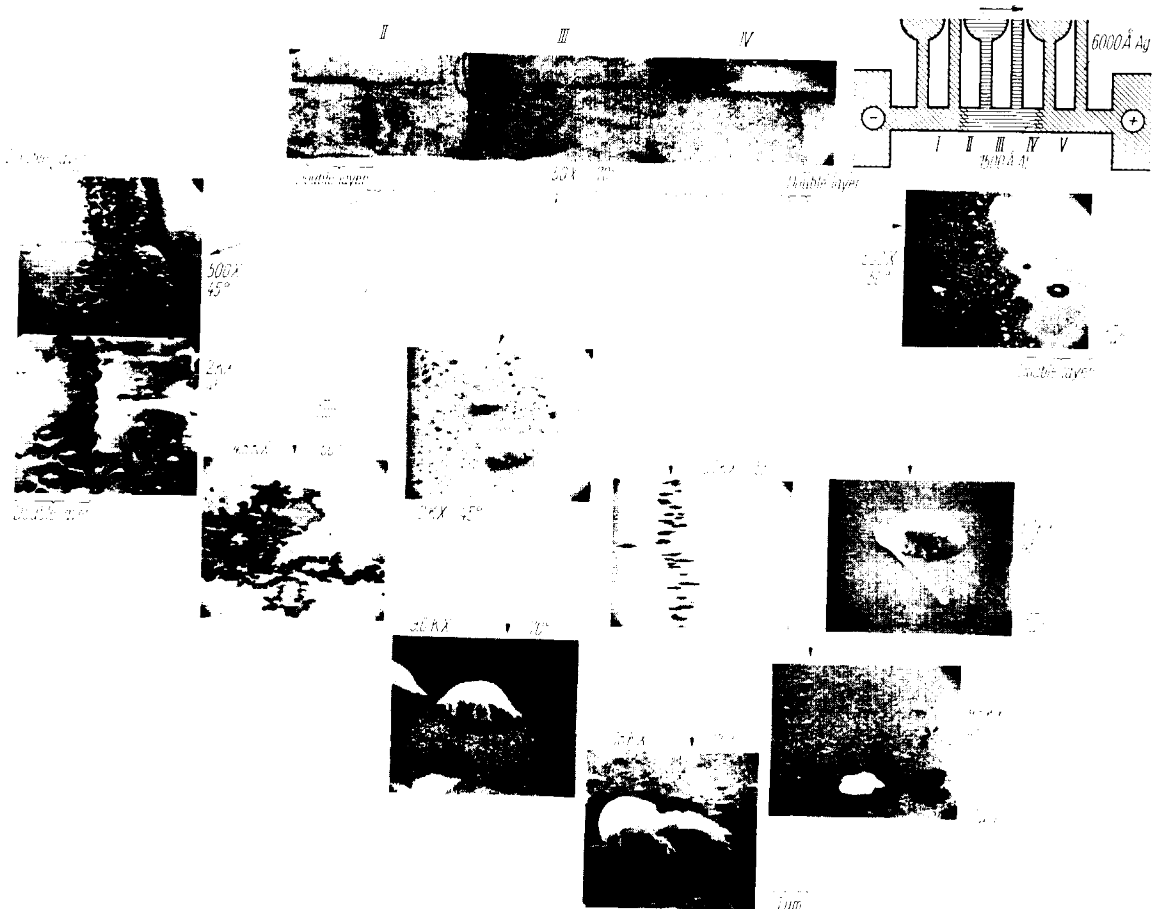

Fig. 3. Scanning electron micrographs of an aluminum sample which was subjected to a current density of 5 · 10⁵ A/cm²